WATTA WELLA RENEWABLE ENERGY PROJECT

Shadow Flicker Assessment

RES Australia Pty Ltd

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Table of contents

EXECUTIVE SUMMARY

DNV has been commissioned by RES Australia Pty Ltd ("RES", or "the Proponent") to independently assess the expected annual shadow flicker durations associated with the development and operation of the wind farm component of the proposed Watta Wella Renewable Energy Project ("WWREP", or "the Project") in western Victoria. The results of the assessment are described in this document.

Background and methodology

DNV has assessed the expected annual shadow flicker durations for the Project in accordance with the Victorian Planning Guidelines [1], and Draft National Wind Farm Development Guidelines [2] (Draft National Guidelines). The methodology used in this study has been informed by these guidelines and various standard industry practices.

The Victorian Planning Guidelines recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling. In addition, the Draft National Guidelines recommend limits of 30 hours per year on the theoretical shadow flicker duration, and 10 hours per year on the actual shadow flicker duration.

A Project layout consisting of 47 wind turbines with a rotor diameter of 178 m and a hub height of 166 m, giving a tip height of 255 m Above Ground Level (AGL), has been considered. These dimensions represent the maximum overall tip height for the maximum rotor and tower hub height dimensions considered for the Project.

There are 67 dwellings that have been identified within 5 km of the Project, 10 of which are associated dwellings belonging to wind farm host landowners.

Outcomes of the assessment

The results of the shadow flicker assessment are summarised in Table 6, which is located at the end of this document.

Based on DNV's modelling, four dwellings are expected to experience some shadow flicker above a moderate level of intensity, three of which are associated dwellings, and one of which is a non-associated dwelling.

Of the three associated dwellings, all of these (H101, H106 and H171) are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling, with one dwelling (H106) significantly exceeding the limit. When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at one of the associated dwellings (H106) is predicted to be above the recommended limit of 10 hours per year within 50 m of the dwelling, with the other associated dwellings all below this limit.

The single non-associated dwelling (H178) is predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. However, when considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at this non-associated dwelling is predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling.

The calculation of the predicted actual shadow flicker duration does not take into account other potential reductions due to low wind speed, vegetation, or other shielding effects around each dwelling.

At all the assessed dwelling locations, the turbine configuration parameters (namely maximum hub height and rotor diameter) used in the modelling will generally be representative of a "worst case" scenario for the wind farm, based on the turbine options that DNV understands the Proponent is considering for the Project. This is discussed further in Section 5.

Considering the above results, some form of mitigation will be required to manage the shadow flicker impacts at affected neighbouring dwellings where the shadow flicker limits are exceeded.

The effects of shadow flicker may be reduced through a number of mitigation measures such as the removal or relocation of turbines, the use of smaller turbines, installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies to shut down turbines when shadow flicker is likely to occur. Shadow flicker exceedances can also potentially be managed through establishing agreements with potentially affected landholders.

A cumulative shadow flicker assessment was also carried out for the Project considering the combined impacts of WWREP and Bulgana Wind Farm turbines. When considering shadow flicker above a moderate level of intensity, it was found that there were no dwellings where the shadow flicker impacts from the WWREP and Bulgana turbines were acting cumulatively.

Blade glint is not expected to be an issue for the Project provided a non-reflective finish is applied to the wind turbine blades.

1 INTRODUCTION

RES Australia Pty Ltd ((“RES”, or “the Proponent”) has commissioned DNV to independently assess the expected annual shadow flicker durations associated with the proposed Watta Wella Renewable Energy Project (“WWREP”, or “the Project”) in western Victoria. The results of this work are reported here. This document has been prepared in accordance with the *Consultancy Agreement Relating to wind monitoring, wind assessment and planning studies for the Watta Wella Renewable Energy Project* established between the Proponent and DNV on 9 December 2020, and is subject to the terms and conditions in that agreement.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the current proposed turbine layout and configuration in general accordance with the Policy and Planning Guidelines for Development of Wind Energy Facilities in Victoria (Victorian Planning Guidelines) prepared by the Victorian Department of Environment, Land, Water and Planning in November 2021 [1], and the National Wind Farm Development Guidelines – Draft (Draft National Guidelines) prepared by the Environment Protection and Heritage Council (EPHC) in July 2010 [2].

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The proposed Project site is located in the Wimmera region in western Victoria, approximately 16 km north east of Stawell and 30 km north of Ararat. An overview of the site location is presented in Figure 1. The site is characterised by open farmland on gently undulating terrain, interspersed with wind breaks and some areas of trees. The Joel Joel Nature Conservation Reserve lies near the southern site boundary and the Wimmera River lies to the east.

High resolution digital elevation data was supplied for the project by the Proponent [3], which was included in the site model. Areas outside of this map region were covered using publicly available SRTM-1 data.

2.2 The Project

2.2.1 Proposed wind farm layout

The Project is proposed to consist of 47 wind turbines [4]. A map of the site with the proposed turbine layout is shown in Figure 2, and the coordinates of the proposed turbine locations are presented in Table 3.

The Project was modelled assuming turbines with a rotor diameter of 178 m and a hub height of 166 m, for a total tip height of 255 m AGL, based on data supplied by the Proponent [5]. DNV understands that these dimensions represent the maximum overall tip height for the maximum rotor and tower hub height dimensions considered for the Project.

2.2.2 Dwelling locations

The locations of dwellings in the vicinity of the Project have been provided by the Proponent [6]. There are 67 dwellings located within 5 km of the Project site boundaries, 10 of which are associated dwellings. Associated dwellings are defined as belonging to wind farm host landowners.

For the purposes of this assessment, DNV has considered all identified dwellings up to 2720 m from Project turbines (which corresponds to 15 times the rotor diameter, or 15D, plus 50 m). Dwellings situated more than 2720 m from turbine locations are considered unlikely to be impacted by shadow flicker, as discussed further in Sections 3.1 and 4.1. DNV has only considered buildings categorised as houses, and has assumed that all of these are inhabited. The coordinates of the dwellings included in the assessment are presented in Table 4, and also presented in Figure 2.

DNV has not carried out a detailed and comprehensive survey of building locations in the area and is relying on information provided by the Proponent.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

The Victorian Planning Guidelines [1], currently state:

> *"The shadow flicker experienced immediately surrounding the area of a dwelling (garden fenced area) must not exceed 30 hours per year as a result of the operation of the wind energy facility."*

In addition, the Draft National Guidelines [2] include recommendations for shadow flicker limits relevant to wind farms in Australia.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration should not exceed 30 hours per year, and that the actual or measured shadow flicker duration should not exceed 10 hours per year. The guidelines also recommend that the shadow flicker duration at a dwelling be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of a dwelling.

As details of the 'garden fenced area' for a dwelling are not readily available, DNV assumes that the evaluation of the maximum shadow flicker duration within 50 m of a dwelling (as required by the Draft National Guidelines) is similar to assessing shadow flicker durations within the 'garden fenced area'. In most cases this approach is expected to be adequate, however it is acknowledged that, in rural areas, the 'garden fenced area' may extend beyond 50 m from a dwelling.

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the Victorian Planning Guidelines or the Draft National Guidelines to assess shadow flicker durations at locations other than in the vicinity of dwellings.

The Draft National Guidelines also provide background information, a proposed methodology, and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

The impact of shadow flicker is typically only significant up to a distance of around 10 rotor diameters from a turbine [7] or approximately 1200 m to 1700 m for modern wind turbines (which typically have rotor diameters of 120 m to 170 m). Beyond this distance limit the shadow is diffused such that the variation in light levels is not likely to be sufficient to cause annoyance. This issue is discussed in the Draft National Guidelines where it is stated that:

> *"Shadow flicker can theoretically extend many kilometres from a wind turbine. However the intensity of the shadows decreases with distance. While acknowledging that different individuals have different levels of sensitivity and may be annoyed by different levels of shadow intensity, these guidelines limit assessment to moderate levels of intensity (i.e., well above the minimum theoretically detectable threshold) commensurate with the nature of the impact and the environment in which it is experienced."*

The Draft National Guidelines therefore suggest a distance equivalent to 265 times the maximum blade chord as an appropriate limit, which corresponds to approximately 1000 m to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of 4 m to 6 m).

3.2 Blade glint

The Draft National Guidelines [2] provide guidance on blade glint and state that:

> *"The sun's light may be reflected from the surface of wind turbine blades. Blade Glint has the potential to annoy people. All major wind turbine manufacturers currently finish their blades with a low reflectivity treatment. This prevents a potentially annoying reflective glint from the surface of the blades and the possibility of a strobing reflection when the turbine blades are spinning. Therefore the risk of blade glint from a new development is considered to be very low."*

4 ASSESSMENT METHODOLOGY

4.1 Shadow flicker

4.1.1 Overview

Shadow flicker may occur under certain combinations of geographical position and time of day, when the sun passes behind the rotating blades of a wind turbine and casts a moving shadow over neighbouring areas. When viewed from a stationary position the moving shadows cause periodic flickering of the light from the sun, giving rise to the phenomenon of 'shadow flicker'.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends upon a number of factors, including:

- the direction of the property relative to the turbine
- the distance from the turbine (the further the observer is from the turbine, the less pronounced the effect will be)
- the wind direction (the shape of the shadow will be determined by the position of the sun relative to the blades which will be oriented to face the wind)
- the turbine height and rotor diameter
- the time of year and day (the position of the sun in the sky)
- the weather conditions (cloud cover reduces the occurrence of shadow flicker).

4.1.2 Theoretical modelled duration

The theoretical number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which incorporates the sun path, topographic variation over the site area, and wind turbine details such as rotor diameter and hub height.

The wind turbines have been modelled assuming they are spherical objects, which is equivalent to assuming the turbines are always oriented perpendicular to the sun-turbine vector. This assumption will mean the model calculates the maximum duration for which there is potential for shadow flicker to occur, up to a specified distance limit.

In line with the methodology proposed in the Draft National Guidelines, DNV has assessed the shadow flicker at the provided dwelling locations and has determined the highest shadow flicker duration within 50 m of each of the provided dwelling location.

Shadow flicker has been calculated at dwellings at heights of 2 m, to represent ground floor windows, and 6 m, to represent second floor windows. The shadow receptors are simulated as fixed points, representing the worst-case scenario, as real windows could be facing a particular direction less affected by shadows cast from the turbines. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute. The shadow flicker map was generated using a temporal resolution of 5 minutes and a spatial resolution of 10 m to reduce computational requirements to acceptable levels.

As part of the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of a shadow cast by a wind turbine that is likely to cause annoyance due to shadow flicker. The UK wind industry considers that 10 rotor diameters is appropriate [7], while the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord as an appropriate limit.

For the current assessment, DNV has applied a maximum shadow length of 10 times the rotor diameter (10D), which corresponds to a distance limit of 1780 m. Under the Draft National Guidelines, this may be conservative for any turbine with a maximum blade chord of less than 6.7 m. Beyond this distance limit, it is assumed that any shadow flicker experienced will be below a "moderate level of intensity" and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker intensities below the "moderate level of intensity" assumed by this distance limit. To account for this possibility, DNV has also assessed the shadow flicker for an increased distance limit of 15 times the rotor diameter (15D), or 2670 m, which should include shadow flicker below a "moderate level of intensity".

The model also makes the following assumptions and simplifications:

- there are clear skies every day of the year
- the blades of the turbines are always perpendicular to the direction of the line of sight from the location of interest to the sun
- the turbines are always rotating.

The first two of these items are addressed in the calculation of the predicted actual shadow flicker duration as described in Section 4.1.4. The third item is not considered but is unlikely to have a significant impact on the results. The settings used to execute the model can be seen in Table 5.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a flat area is shown in Figure 3. The geometry of the shadow flicker map can be characterised as a butterfly shape, with the four protruding lobes corresponding to slowing of solar north-south travel around the summer and winter solstices for morning and evening. The lobes to the north of the indicative turbine location result from the summer months and conversely the lobes to the south result from the winter months. The lobes to the west result from morning sun while the lobes to the east result from evening sun. When the sun is low in the sky, the length of shadows cast by the turbine increases, increasing the area around the turbine affected by shadow flicker.

4.1.3 Factors affecting duration

Shadow flicker duration calculated in this manner overestimates the annual number of hours of shadow flicker experienced at a specified location for several reasons, including:

1. The wind turbine will not always be oriented such that its rotor is in the worst-case position (i.e., perpendicular to the sun-turbine vector). Any other rotor orientation will reduce the area of the projected shadow and hence the shadow flicker duration.

   The wind speed frequency distribution or wind rose at the site can be used to determine probable turbine orientation and to calculate the resulting reduction in shadow flicker duration.

2. The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker.

   Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover and to provide an indication of the resulting reduction in shadow flicker duration.

3. Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a wind turbine.

The length of the shadow cast by a wind turbine is dependent on the degree that direct sunlight is diffused, which is in turn dependent on the amount of dispersants (humidity, smoke, and other aerosols) in the path between the light source (sun) and the receiver.

4. The modelling of the wind turbine rotor as a sphere rather than individual blades results in an overestimate of shadow flicker duration.

   Turbine blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the turbine blade, and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade.

5. The analysis does not consider that when the sun is positioned directly behind the wind turbine hub, there is no variation in light intensity at the receiver location and therefore no shadow flicker.

6. The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the wind turbine, and therefore reduce the incidence of shadow flicker.

7. Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce the annual shadow flicker duration.

4.1.4 Predicted actual duration

As discussed above in Section 4.1.3, there are a number of factors which may reduce the incidence of shadow flicker that are not taken into account in the calculation of the theoretical shadow flicker duration. An attempt has been made to quantify the likely reduction in shadow flicker duration due to cloud cover and, therefore, produce a prediction of the actual shadow flicker duration likely to be experienced at a receptor.

Cloud cover is typically measured in 'oktas', effectively eighths of the sky covered with cloud. DNV has obtained data from the following Bureau of Meteorology (BoM) stations:

Table 1 Sources of cloud data used in the assessment

Weather station	Station ID	Distance to site [approx. km]
Stawell [8]	079080	15.6
Ararat Prison [9]	089085	29.6
Maryborough [10]	088043	69.2
Ballarat Aerodrome [11]	089002	92.6

The number of oktas of cloud cover visible across the sky at these stations is recorded twice daily, at 9 am and 3 pm, and the observations are provided as monthly averages. After averaging the 9 am and 3 pm observations for the stations considered, the results indicate that the average monthly cloud cover in the region ranges between 43% and 71%, and the average annual cloud cover is approximately 60%. This means that on an average day, 60% of the sky in the vicinity of the wind farm is covered with clouds. Although it is not possible to definitively calculate the effect of cloud cover on shadow flicker duration, a reduction in the shadow flicker duration proportional to the amount of cloud cover is a reasonable assumption.

Similarly, turbine orientation can have an impact on the shadow flicker duration. The shadow flicker duration is greatest when the turbine rotor plane is approximately perpendicular to a line joining the sun and an observer, and a minimum when the rotor plane is approximately parallel to a line joining the sun and an observer. Wind direction frequency distributions for the site were derived from wind measurements at the site were provided by the Proponent [12] and used to estimate the reduction in shadow flicker duration due to rotor orientation. The measured wind rose is shown overlaid on the indicative shadow flicker map in Figure 3. An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation was conducted on an annual basis.

It should be noted that the method prescribed by the Draft National Guidelines for assessing actual shadow flicker duration recommends that only reductions due to cloud cover, and not turbine orientation, be included. However, DNV considers that the additional reduction due to turbine orientation is appropriate as the projected area of the turbine, and therefore the expected shadow flicker duration, is reduced when the turbine rotor is not perpendicular to the line joining the sun and dwelling. Due to limitations in the availability of suitable cloud cover data, the methodology used in this assessment also deviates somewhat from the method recommended by the Draft National Guidelines for assessing the reduction in shadow flicker due to cloud cover. However, considering the available cloud cover data, the approach described above is deemed to provide a reasonable estimate of the likely impact of cloud cover on the shadow flicker duration.

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in calculating the shadow flicker duration. Similarly, turbine shutdown has not been considered.

4.1.5 Cumulative impact assessment

DNV notes that the Project is located in an area of high wind farm development activity, with multiple operational wind farms nearby. Consequently, it is possible that some dwellings near the Project could experience cumulative impacts from neighbouring wind farms.

The nearest wind farm developments to the Project are summarised in Table 2 below, based on information provided by the Proponent [13] and publicly available sources [14] [15] [16].

Table 2 Other wind farm developments located in the vicinity of the Project site

Wind farm	Status	Location
Bulgana Wind Farm	Operating	Adjacent to the WWREP southern boundary (with the nearest Bulgana turbine < 500 m from WWREP turbines)
Crowlands Wind Farm	Operating	12 km southeast of the WWREP boundary
Ararat Wind Farm	Operating	13 km south of the WWREP boundary

At typical distances from the Project that shadow flicker could potentially be an issue, only turbines from the Bulgana Wind Farm are close enough to potentially cause cumulative shadow flicker impacts in combination with WWREP turbines at nearby dwellings. The Bulgana turbines nearest to the Project are shown in Figure 2. Based on publicly available sources of data, it is understood that the Bulgana turbines consist of Siemens Gamesa SG 3.4-132 turbines with a rotor diameter of 132 m [17] and hub height of 114 m [18], giving a tip height of 180 m AGL.

For the purposes of this assessment, if it is conservatively assumed that Bulgana turbines generate shadow flicker at similar distances to WWREP turbines, up to two dwellings could potentially be affected by cumulative shadow flicker (H120 and H243). The shadow flicker areas which could potentially lead to cumulative impacts are shown in Figure 6.

Neither of these dwellings will be affected by shadow flicker generated from turbines at both wind farms if only shadow flicker above a moderate levels of intensity is considered. However these dwellings could potentially be subject to shadow flicker from both wind farms if shadow flicker above *and* below a moderate level of intensity is considered, depending on the distance of each dwelling from specific WWREP and Bulgana turbines.

The potential for cumulative impacts have been assessed using distance thresholds of up to 1780 m (i.e., 10 times the rotor diameter of WWREP turbines, plus 50 m) from all WWREP and Bulgana turbines when considering shadow flicker above a moderate level of intensity only, and up to 2720 m (i.e. 15 times the rotor diameter of WWREP turbines, plus 50 m) when considering shadow flicker above and below a moderate level of intensity.

4.2 Blade glint

Blade glint involves the regular reflection of sun off rotating turbine blades. Its occurrence depends on a combination of circumstances arising from the orientation of the nacelle, angle of the blade and the angle of the sun. The reflectiveness of the surface of the blades is also important. Blade glint is not generally a problem for modern wind turbines, provided the blades are coated with a non-reflective paint, and it is not considered further here.

5 ASSESSMENT RESULTS

5.1 Shadow flicker

5.1.1 Considering WWREP turbines only

Shadow flicker assessments were carried out at the dwelling locations, or "receptors", as outlined in Table 4.

The theoretical and predicted actual shadow flicker durations at all dwelling locations identified to be affected by shadow flicker considering WWREP turbines only are presented in Table 6. The maximum shadow flicker durations within 50 m of the dwellings are also presented in this table. Furthermore, the results are shown in the form of shadow flicker maps in Figure 4 and Figure 5. The shadow flicker values presented in these maps represent the maximum between the results at 2 m and 6 m above ground for each modelled grid point.

Based on DNV's modelling, four dwellings are expected to experience some shadow flicker above a moderate level of intensity, three of which are associated dwellings, and one of which is a non-associated dwelling.

Of the three associated dwellings, all of these (H101, H106 and H171) are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling, with one dwelling (H106) significantly exceeding the limit. When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at one of the associated dwellings (H106) is predicted to be above the recommended limit of 10 hours per year within 50 m of the dwelling, with the other associated dwellings all below this limit.

The single non-associated dwelling (H178) is predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. However, when considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at this non-associated dwelling is predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be below a "moderate level of intensity" and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker intensities below the "moderate level of intensity" assumed by this distance limit. To account for this possibility, and although not part of the methodology outlined in the Draft National Guidelines, DNV has also assessed the shadow flicker impacts for the Project for an increased distance limit that is intended to include shadow flicker below a "moderate level of intensity". For the purpose of this assessment, the distance limit has been increased by 50% (to 15D), and the results of this additional assessment are illustrated in the map presented in Figure 4. These results indicate that 18 dwellings have the potential to be exposed to shadow flicker below a "moderate level of intensity", in addition to the four dwellings above which have been predicted to experience shadow flicker above a moderate level of intensity. These dwellings are noted in Table 6.

At all the assessed dwelling locations, the turbine configuration parameters (namely maximum hub height and rotor diameter) used in the modelling will generally be representative of a "worst case" scenario for the wind farm, based on the turbine options that DNV understands the Proponent is considering for the wind farm.

If a turbine with smaller rotor dimensions is selected but the hub height is unchanged, the shadow flicker durations will reduce from the reported results.

As a check on the modelled shadow flicker results, to cover the range of hub heights being considered by the Proponent for the site, DNV also performed modelling considering a hub height of 149 m (with a rotor diameter of 178 m), giving a lower rotor tip height of 60 m and upper rotor tip height of 238 m (compared to a lower and upper rotor tip height of 77 m and 255 m respectively, for a hub height of 166 m). At distances from the wind farm at which shadow flicker above a moderate level of shadow flicker could occur, it was found that at all affected dwellings the theoretical and actual shadow flicker results for the 166 m hub height option were higher than for the 149 m hub height option.

5.1.2 Cumulative impact assessment

A cumulative shadow flicker impact assessment was carried out at two dwelling locations, H120 and H243, which were identified as potential candidates for cumulative shadow flicker based on turbine distances.

The theoretical and predicted actual cumulative shadow flicker durations at the affected dwelling locations, considering shadow flicker above a moderate level of intensity only, are presented in Table 7. The maximum shadow flicker durations within 50 m of the dwellings are also presented in this table.

Dwelling H120 is not predicted to experience shadow flicker above or below a moderate level of intensity from WWREP turbines, but may experience some shadow flicker above a moderate level of intensity from Bulgana turbines.

Dwelling H243 is not predicted to experience shadow flicker above a moderate level of intensity from WWREP or Bulgana turbines, but may experience some shadow flicker below a moderate level of intensity from both WWREP and Bulgana turbines.

Therefore, when considering shadow flicker above a moderate level of intensity, it was found that there were no dwellings where the shadow flicker impacts from the WWREP and Bulgana turbines were acting cumulatively.

5.1.3 Mitigation

Considering the above results, some form of mitigation will be required to manage the shadow flicker impacts at affected neighbouring dwellings where the shadow flicker limits are exceeded.

The effects of shadow flicker may be reduced through a number of mitigation measures such as the removal or relocation of turbines, the use of smaller (rotor) turbines, installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies to shut down turbines when shadow flicker is likely to occur.

If not already in place, another option to manage shadow flicker restrictions is for the Proponent to establish agreements with the landowners of dwellings where shadow flicker is predicted to occur above the recommended limits, which includes an agreed acceptable shadow flicker duration. Such agreements can be used to manage the acceptable shadow flicker durations at these locations. It is also recommended that as part of this process these landowners are made aware of the shadow flicker durations that may be experienced at their dwellings without mitigation.

5.2 Blade glint

As discussed in Section 4.2, blade glint is not expected to be an issue for the project provided a non-reflective finish is applied to the wind turbine blades.

6 CONCLUSIONS

A shadow flicker assessment was carried out at all dwelling locations in the vicinity of the Project. For the purpose of this assessment, DNV has considered a layout consisting of 47 turbines with a rotor diameter of 178 m and hub height of 166 m for a total tip height of 255 m AGL. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 6.

Based on DNV's modelling, four dwellings are expected to experience some shadow flicker above a moderate level of intensity, three of which are associated dwellings, and one of which is a non-associated dwelling.

Of the three associated dwellings, all of these (H101, H106 and H171) are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling, with one dwelling (H106) significantly exceeding the limit. When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at one of the associated dwellings (H106) is predicted to be above the recommended limit of 10 hours per year within 50 m of the dwelling, with the other associated dwellings all below this limit.

The single non-associated dwelling (H178) is predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. However, when considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at this non-associated dwelling is predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling.

A cumulative shadow flicker assessment was also carried out for the Project considering the combined impacts of WWREP and Bulgana Wind Farm turbines. When considering shadow flicker above a moderate level of intensity, it was found that there were no dwellings where the shadow flicker impacts from the WWREP and Bulgana turbines were acting cumulatively.

Considering the above results, some form of mitigation will be required to manage the shadow flicker impacts at affected neighbouring dwellings where the shadow flicker limits are exceeded.

Since a non-reflective finish is proposed for the wind turbine blades, blade glint is not expected to be an issue for the Project.

7 REFERENCES

[1] Department of Environment, Land, Water and Planning, “Development of Wind Energy Facilities in Victoria, Policy and Planning Guidelines,” November 2021.

[2] Environment Protection and Heritage Council (EPHC), “National Wind Farm Development Guidelines - Draft,” July 2010.

[3] “Watta Wella - DEM,” Email from N Kelly (RES) to J Jobin (DNV), 4 February 2021.

[4] “'WattaWella_Turbine_Coordinates.xlsx',” attachment to email from M Kalocsay (RES) to J Jobin (DNV), 11 May 2022.

[5] Email "RE: Watta Wella consultancy agreement" sent from N Kelly (RES) to T. Gilbert (DNV), 4 January 2021.

[6] “'WW_House_Layer_5km_260521.shp',” attachment to email from N Kelly (RES) to F Dahhan (DNV), 31 May 2021.

[7] “Planning for Renewable Energy - A Companion Guide to PPS22,” Office of the Deputy Prime Minister, UK, 2004.

[8] Bureau of Meteorology, “Climate statistics for Australian locations - Stawell,” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_079080_All.shtml. [Accessed 22 July 2021].

[9] Bureau of Meteorology, “Climate statistics for Australian locations - Ararat Prison,” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_089085_All.shtml. [Accessed 22 July 2021].

[10] Bureau of Meteorology, “Climate statistics for Australian locations - Maryborough,” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_088043_All.shtml. [Accessed 22 July 2021].

[11] Bureau of Meteorology, “Climate statistics for Australian locations - Ballarat Aerodrome,” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_089002_All.shtml. [Accessed 22 July 2021].

[12] “DNV GL - Watta Wella Datapack 30032021.7z,” attachment to email "RE: Watta Wella - Wind resource grids" from N Kelly (RES) to M. Quan (DNV), 31 March 2021.

[13] “'CRL Turbine Layout', ;RE As built Bulgana wind turbine locations',” attachments to email from N Kelly (RES) to F Dahhan (DNV), 24 June 2021.

[14] Bulgana Green Power Hub, [Online]. Available: https://bulganagreenpowerhub.com.au/. [Accessed 8 June 2021].

[15] Pearce Geotech, “Crowlands Wind Farm,” [Online]. Available: https://www.pearcegeotech.com.au/projects/crowlands-wind-farm/. [Accessed 23 June 2021].

[16] Ararat Wind Farm, “About,” [Online]. Available: https://www.ararat-windfarm.com/about/. [Accessed 18 July 2021].

[17] Siemens Gamesa, [Online]. Available: https://www.siemensgamesa.com/en-int/newsroom/2018/04/siemens-gamesa-to-build-a-pioneering-194-mw-wind-farm-in-australia. [Accessed 20 July 2021].

[18] Keppel Prince, [Online]. Available: https://keppelprince.com.au/projects/company-name-b/. [Accessed 20 July 2021].

LIST OF TABLES

Table 3 Proposed turbine layout for the Project site [4]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
T1	669459	5901183	253	T25	672661	5899189	237
T2	669739	5905759	203	T26	674422	5902140	217
T3	670372	5899921	257	T27	674117	5903596	212
T4	670925	5902384	219	T28	670360	5906355	201
T5	670596	5906790	204	T29	671473	5905348	205
T6	671289	5905879	212	T30	674061	5902768	219
T7	672673	5900064	233	T31	673199	5904306	219
T8	670805	5899714	241	T32	670760	5901179	234
T9	671159	5901752	232	T33	672093	5902672	212
T10	671555	5899832	222	T34	674618	5898439	241
T11	673180	5903124	229	T35	669450	5900502	266
T12	670251	5905690	202	T36	674735	5902541	215
T13	674768	5898162	236	T37	675689	5898381	225
T14	669836	5900213	253	T38	677420	5900550	229
T15	672717	5903407	228	T39	678084	5900510	218
T16	672104	5904218	227	T40	671250	5903823	208
T17	671066	5903269	210	T41	671462	5902907	211
T18	671704	5906053	205	T42	669486	5899801	262
T19	672275	5905826	207	T43	672616	5905074	213
T20	675224	5898324	229	T44	670152	5900938	252
T21	671331	5900081	232	T45	673604	5903372	218
T22	673010	5900287	240	T46	670885	5906375	211
T23	674321	5897611	259	T47	670730	5903882	208
T24	673145	5899183	246				

1. Coordinate system: MGA zone 54, GDA94 datum.

Table 4 Dwellings within 2720 m of turbines at the Project site [6]

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Landowner status	Nearest turbine	
				Distance (km)	Turbine ID
H059	667593	5906565	Non-associated	2.3	T2
H061	667832	5905304	Non-associated	2.0	T2
H062	667892	5902287	Non-associated	1.9	T1
H065	667935	5903141	Non-associated	2.5	T1
H068	668056	5903838	Non-associated	2.6	T2
H072	668066	5904348	Non-associated	2.2	T2
H075	668127	5907399	Non-associated	2.3	T2
H079	668246	5902202	Non-associated	1.6	T1
H082	668307	5903398	Non-associated	2.5	T47
H085	668397	5903953	Non-associated	2.3	T2
H086	668400	5904575	Non-associated	1.8	T2
H090	668508	5904151	Non-associated	2.0	T2
H101	669099	5907458	Associated	1.1	T1
H106	669752	5902272	Associated	2.5	T8
H120	670958	5897218	Associated	2.2	T5
H131	672066	5908386	Associated	2.3	T19
H159	673775	5907532	Associated	1.7	T36
H161	675005	5900349	Non-associated	1.5	T36
H171	676130	5901653	Associated	1.6	T38
H178	676186	5903029	Non-associated	2.2	T36
H188	676351	5901672	Non-associated	1.9	T38
H192	676591	5903697	Non-associated	1.5	T38
H212	677000	5902379	Non-associated	2.2	T39
H218	677145	5902054	Non-associated	2.3	T39
H224	678366	5898547	Associated	1.6	T37
H229	678874	5902526	Non-associated	2.3	T2
H231	679221	5898491	Non-associated	2.0	T2
H243	676661	5897096	Non-associated	1.9	T1

1. Coordinate system: MGA zone 54, GDA94 datum.
2. Associated dwellings are indicated by *underlined italic text*.

Table 5 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1780 m
Year of calculation	2034
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (disc for turbine orientation reduction calculation)
Sun modelled as	Disc
Offset between rotor and tower	None
Receptor height (single storey)	2 m
Receptor height (double storey)	6 m
Locations used for determining maximum shadow flicker within 50 m of each dwelling	8 points evenly spaced (every 45°) on 25 m and 50 m radius circles centred on the provided dwelling location

Table 6 Theoretical and predicted actual annual shadow flicker duration to 10D distance (WWREP turbines only)

Dwelling ID[1]	Easting[2] [m]	Northing[2] [m]	Landowner status	Contributing turbines	Theoretical annual				Predicted actual annual[3]			
					At dwelling [hr/yr]		Max within 50 m [hr/yr]		At dwelling [hr/yr]		Max within 50 m [hr/yr]	
					2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m
H059 [4]	667593	5906565	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H061 [4]	667832	5905304	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H062 [4]	667892	5902287	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H068 [4]	668056	5903838	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H072 [4]	668066	5904348	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H075 [4]	668127	5907399	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H079 [4]	668246	5902202	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H082 [4]	668307	5903398	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H085 [4]	668397	5903953	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H086 [4]	668400	5904575	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H090 [4]	668508	5904151	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H101	669099	5907458	Associated	T05	**30.4**	**30.1**	**32.3**	**32.0**	9.0	9.0	9.4	9.3
H106	669752	5902272	Associated	T04 T09 T17 T41	**55.3**	**53.4**	**81.2**	**79.5**	**12.1**	**11.8**	**18.0**	**17.6**
H161 [4]	675005	5900349	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H171	676130	5901653	Associated	T26 T36	**40.8**	**40.2**	**44.3**	**43.8**	7.6	7.5	8.8	8.6
H178	676186	5903029	Non-associated	T36	26.9	26.1	**35.2**	**34.9**	6.6	6.4	9.2	8.9
H188 [4]	676351	5901672	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H192 [4]	676591	5903697	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H212 [4]	677000	5902379	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H218 [4]	677145	5902054	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H224 [4]	678366	5898547	Associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H243 [4]	676661	5897096	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recommended duration limits (hr/yr)					***30***	***30***	***30***	***30***	***10***	***10***	***10***	***10***

1. Dwellings identified in Table 4 for which there is no theoretical shadow flicker occurrence up to a distance limit of 15 times the rotor diameter have been omitted from this table.
2. Coordinate system: MGA zone 54, GDA94 datum.
3. Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.
4. Dwelling is not predicted to experience any shadow flicker above a moderate level of intensity, but may experience some shadow flicker below a moderate level of intensity.

Table 7 Theoretical and predicted actual annual shadow flicker duration to 10D distance (cumulative impacts)

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Landowner status	Contributing turbines	Theoretical annual				Predicted actual annual[2]			
					At dwelling [hr/yr]		Max within 50 m [hr/yr]		At dwelling [hr/yr]		Max within 50 m [hr/yr]	
					2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m
H120 [3]	670958	5897218	Associated	BU01, BU02	13.5	13.0	15.0	14.5	3.3	3.2	3.7	3.5
H243 [4]	676661	5897096	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recommended duration limits (hr/yr)					***30***	***30***	***30***	***30***	***10***	***10***	***10***	***10***

1. Coordinate system: MGA zone 54, GDA94 datum.
2. Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.
3. Dwelling is not predicted to experience shadow flicker above or below a moderate level of intensity from WWREP turbines, but may experience some shadow flicker above a moderate level of intensity from Bulgana turbines.
4. Dwelling is not predicted to experience shadow flicker above a moderate level of intensity from WWREP or Bulgana turbines, but may experience some shadow flicker below a moderate level of intensity from both WWREP and Bulgana turbines.

LIST OF FIGURES

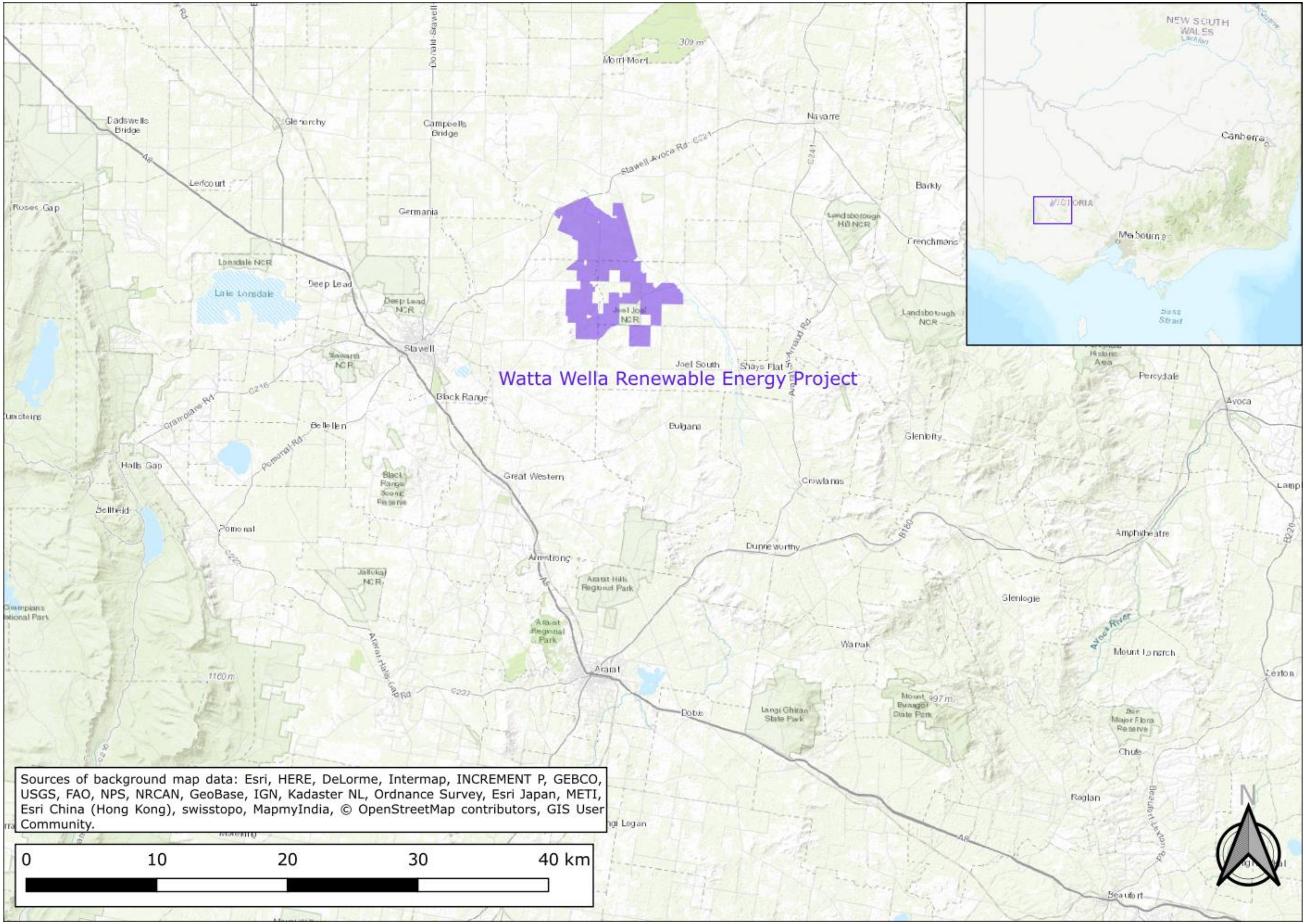


Figure 1 Location of the Project

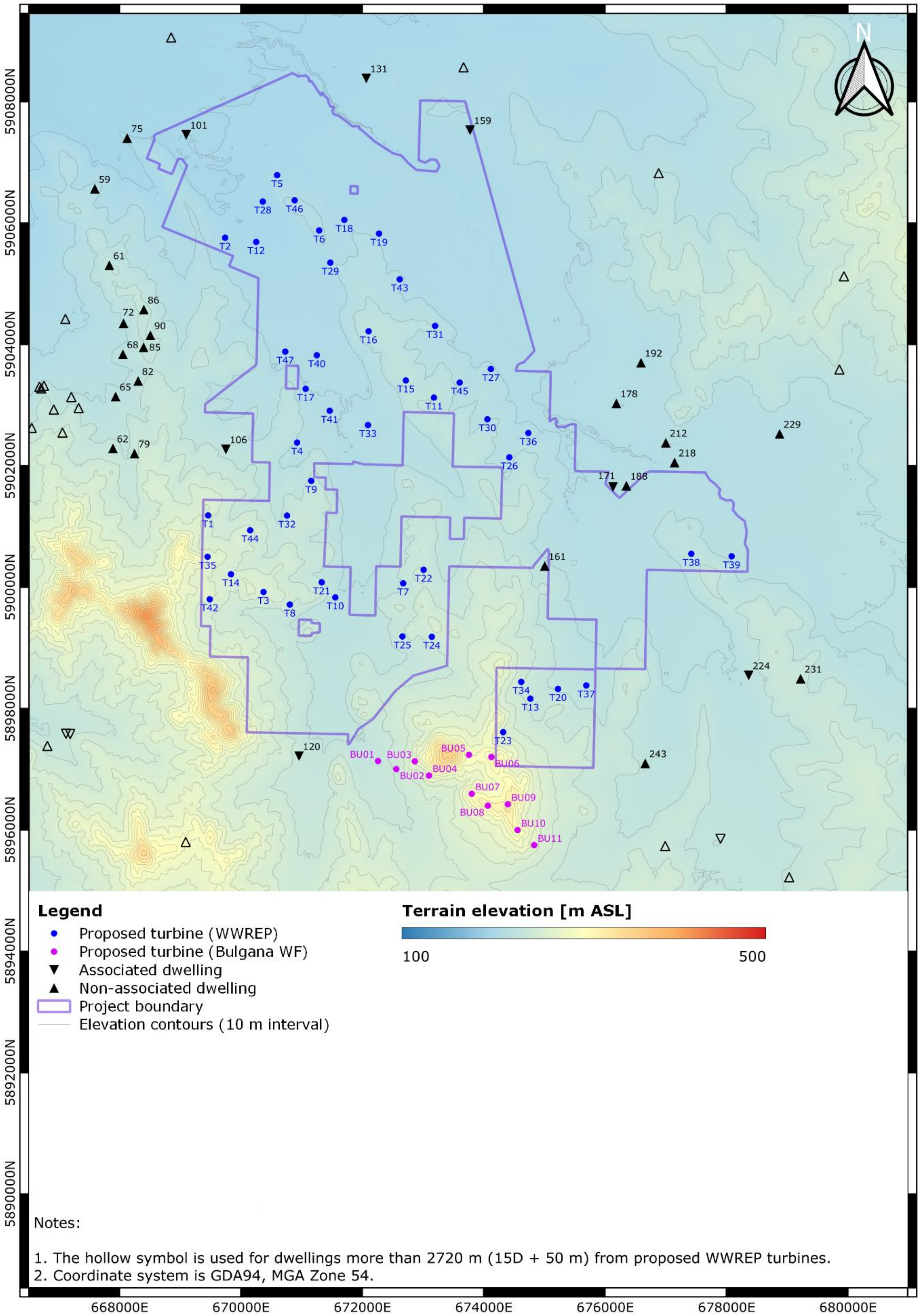


Figure 2 Site layout, showing wind turbines, dwellings and elevations

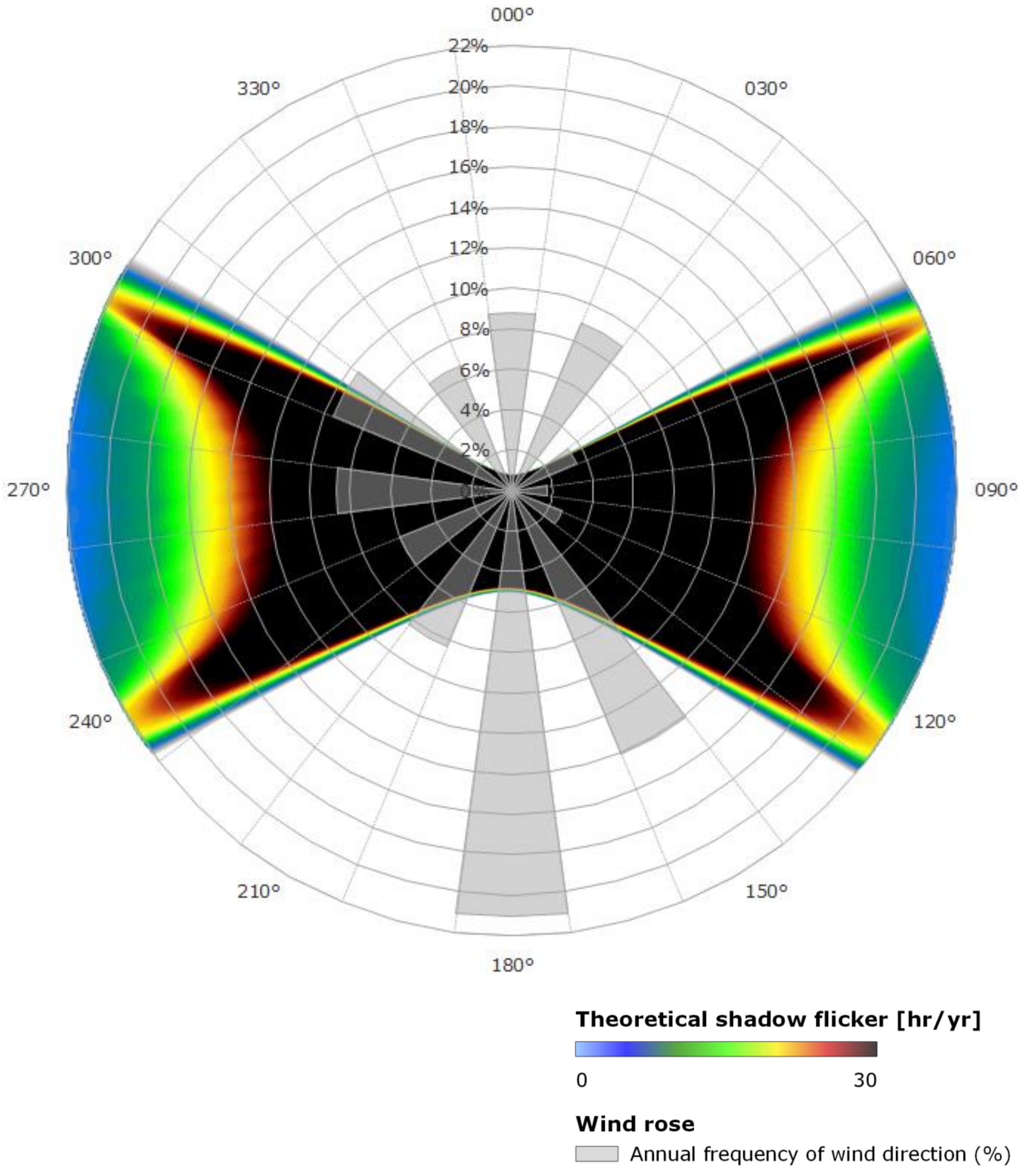


Figure 3 Indicative shadow flicker map and wind direction frequency distribution

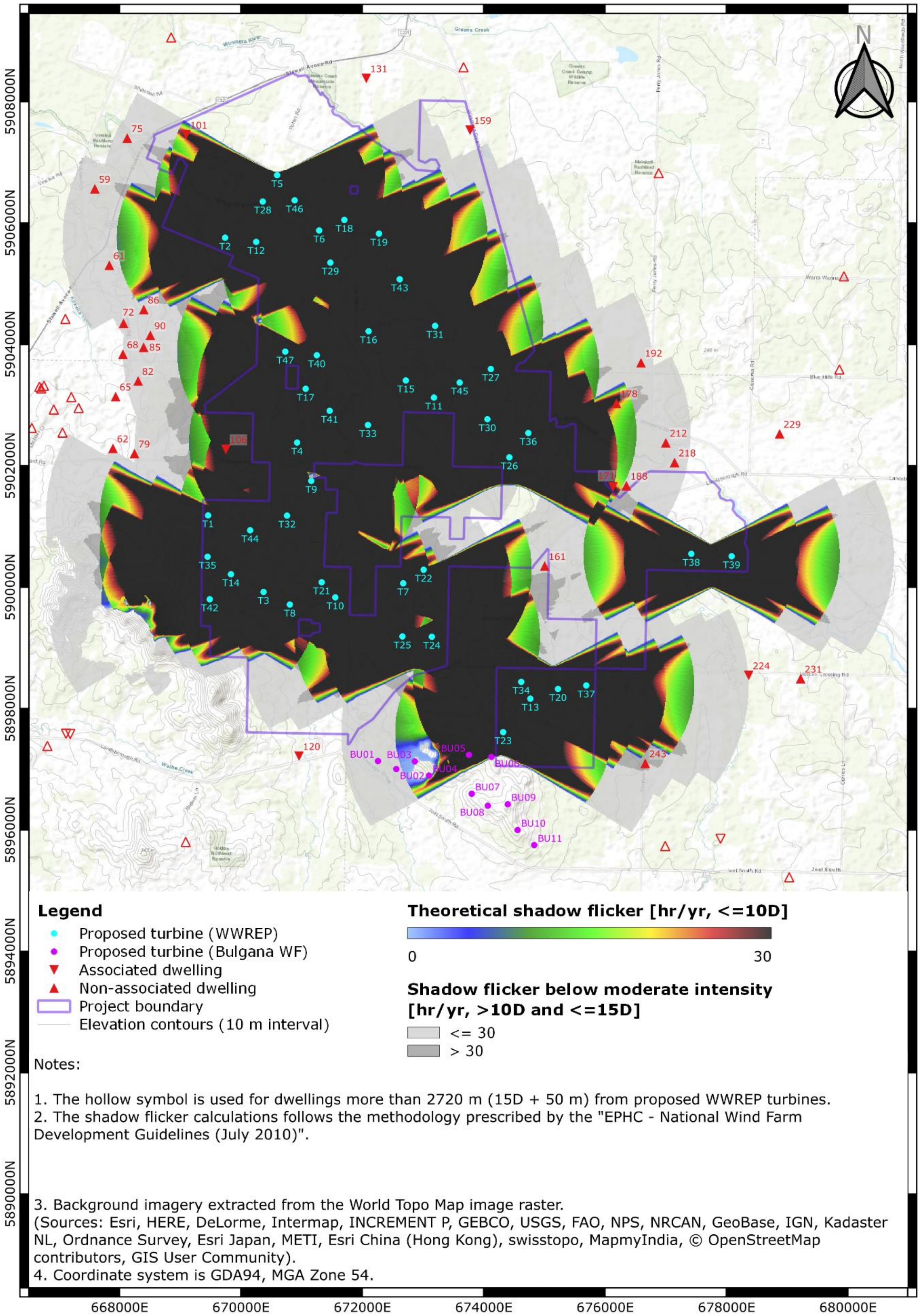
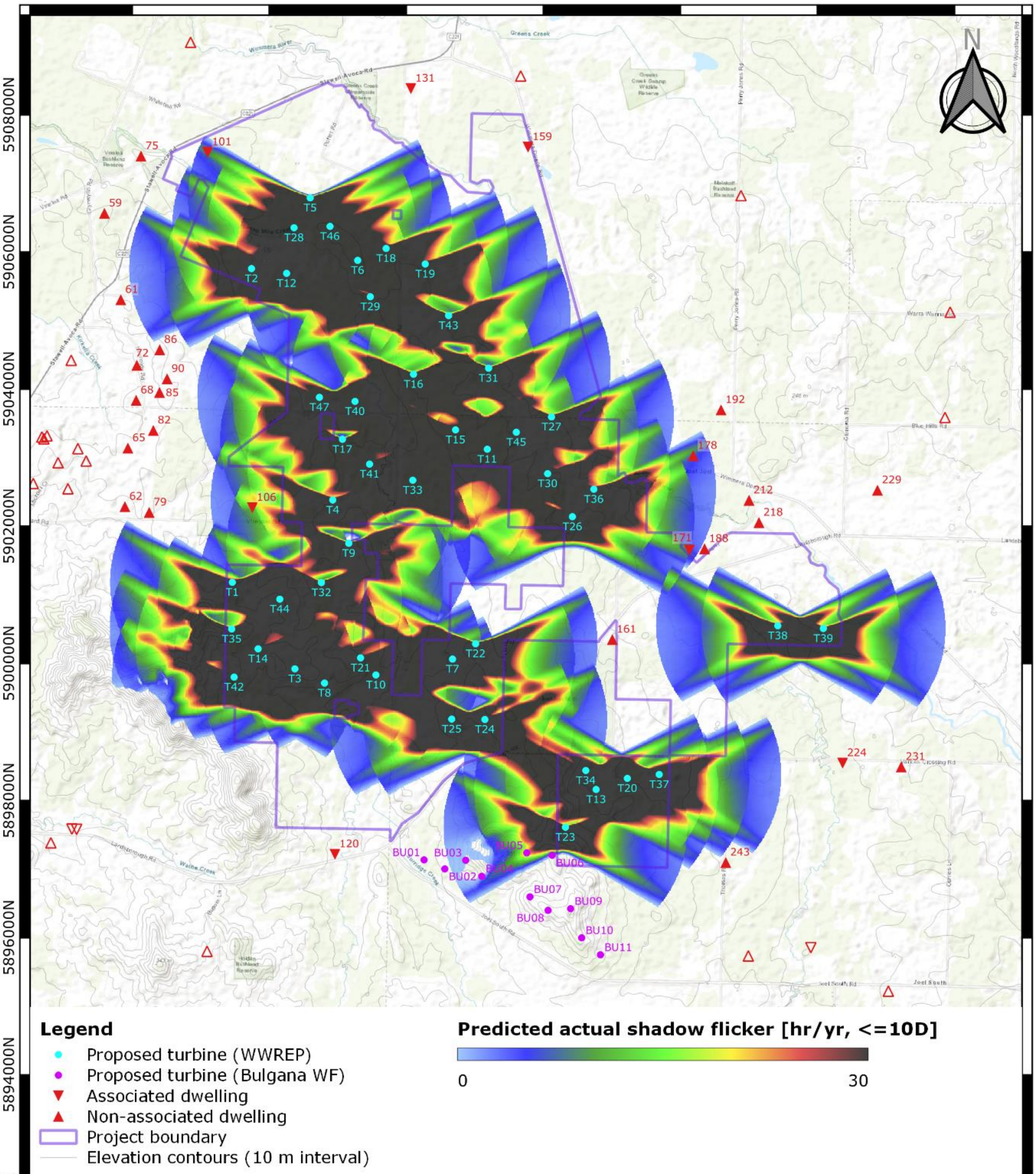


Figure 4 Theoretical annual shadow flicker duration map



Notes:

1. The hollow symbol is used for dwellings more than 2720 m (15D + 50 m) from proposed WWREP turbines.
2. The shadow flicker calculations follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines (July 2010)".
3. The predicted actual shadow flicker duration considers reduction derived from cloud coverage, obtained from surrounding Bureau of Meteorology stations, and rotor orientation, defined by the site monitoring masts wind direction distribution.
4. Background imagery extracted from the World Topo Map image raster.
(Sources: Esri, HERE, DeLorme, Intermap, INCREMENT P, GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, GIS User Community).
5. Coordinate system is GDA94, MGA Zone 54 .

Figure 5 Predicted actual annual shadow flicker duration map

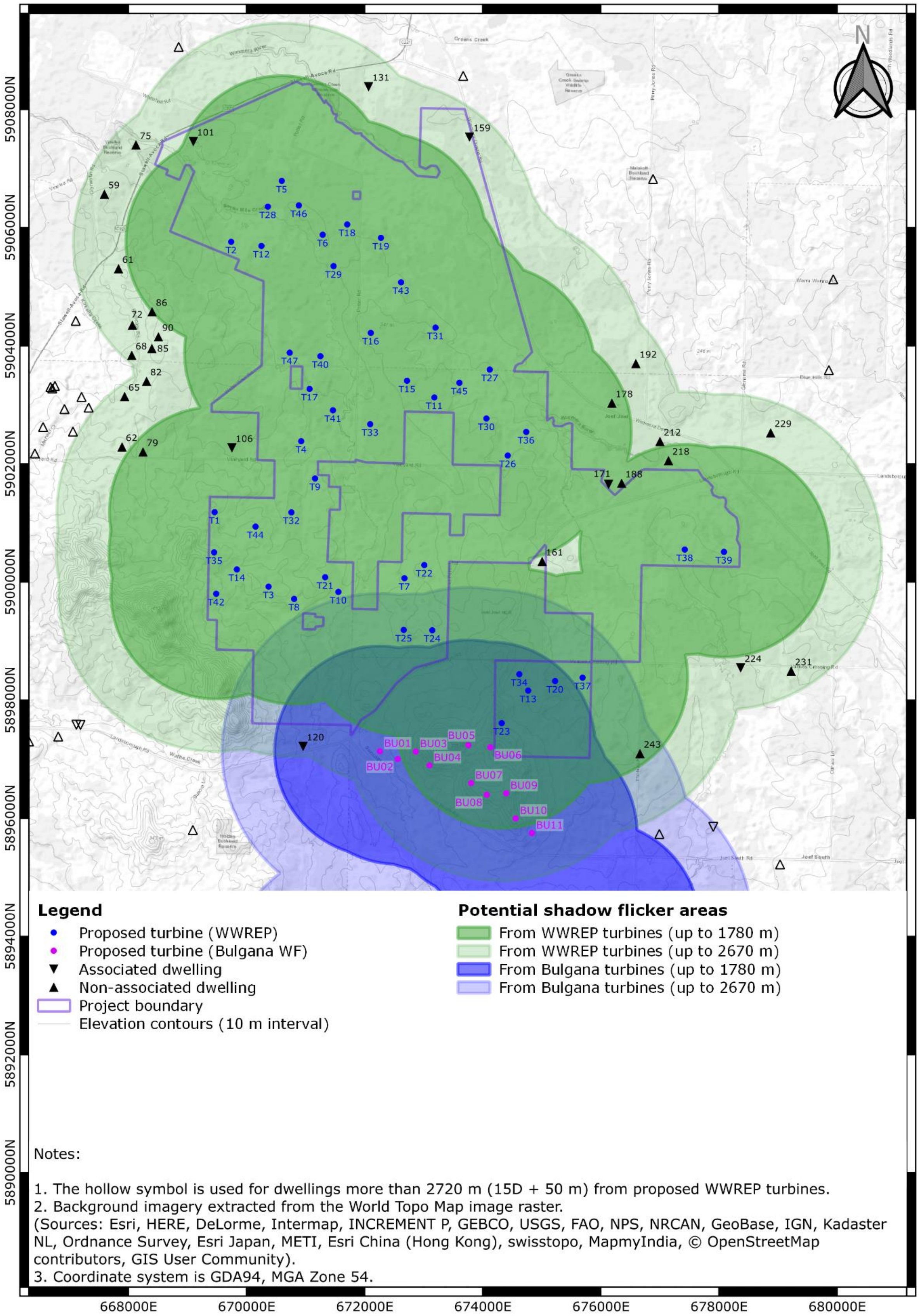


Figure 6 Potential areas for shadow flicker (cumulative impacts)

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